JPL PUBLICATION 80-3

Traction Studies of Northeast Corridor Rail Passenger Service

Executive Summary

T.W. Macie

J.A. Stallkamp

March 15, 1980

Prepared for

U.S. Department of Transportation
Federal Railroad Administration
Office of Research and Development

Through an agreement with
National Aeronautics and Space Administration

by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JET PROPULSION LABORATORY *California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103*

April 17, 1980

Refer to: TWM:db

Gentlemen:

At the request of Mr. Matthew Guarino, Jr., Program Manager Electrical Traction, OR&D, FRA in Washington, D.C., enclosed please find the recently published Traction Studies of Northeast Corridor Rail Passenger Service.

Very truly yours,

JET PROPULSION LABORATORY

Tod W. Macie

Tad W. Macie, Manager
Electrical Traction Studies
Electrical Power & Propulsion Section

TWM:db
Enc.

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Prepared by the Jet Propulsion Laboratory, California Institute of Technology, for the Department of Transportation, Federal Railroad Administration, Office of Research and Development, through Reimbursable Agreement AR-84290, with the National Aeronautics and Space Administration.

PREFACE

A two-year-long study of Northeast Corridor (NEC) Rail Passenger Service operations was carried out at JPL under contract to the Federal Railroad Administration. Various aspects of the study were published in the form of individual letter reports, as listed on page 57.

This document offers a brief summary of those reports.

INTRODUCTION

The enabling legislation of 1976 for improvement of service in the NEC requires a schedule of 2 h 40 min between Washington and New York City by 1981 and 3 h 40 min between NYC and Boston, when the electrification is completed.

Various options of the NEC operation that may satisfy the legislation were investigated, particularly in terms of travel time and energy consumption. NEC operations were compared with overseas systems and practices. The emerging new technology of AC traction was also evaluated.

The work summarized in this report was performed by the Control and Energy Conversion Division of the Jet Propulsion Laboratory, under the cognizance of the JPL Office of Energy and Technology Applications.

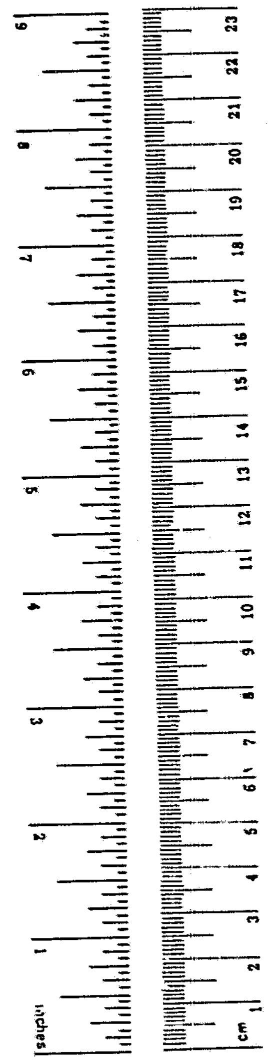
TABLE OF CONTENTS

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

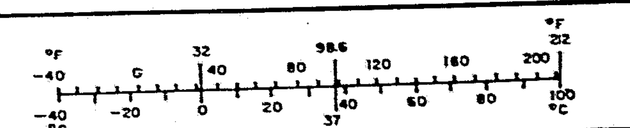
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

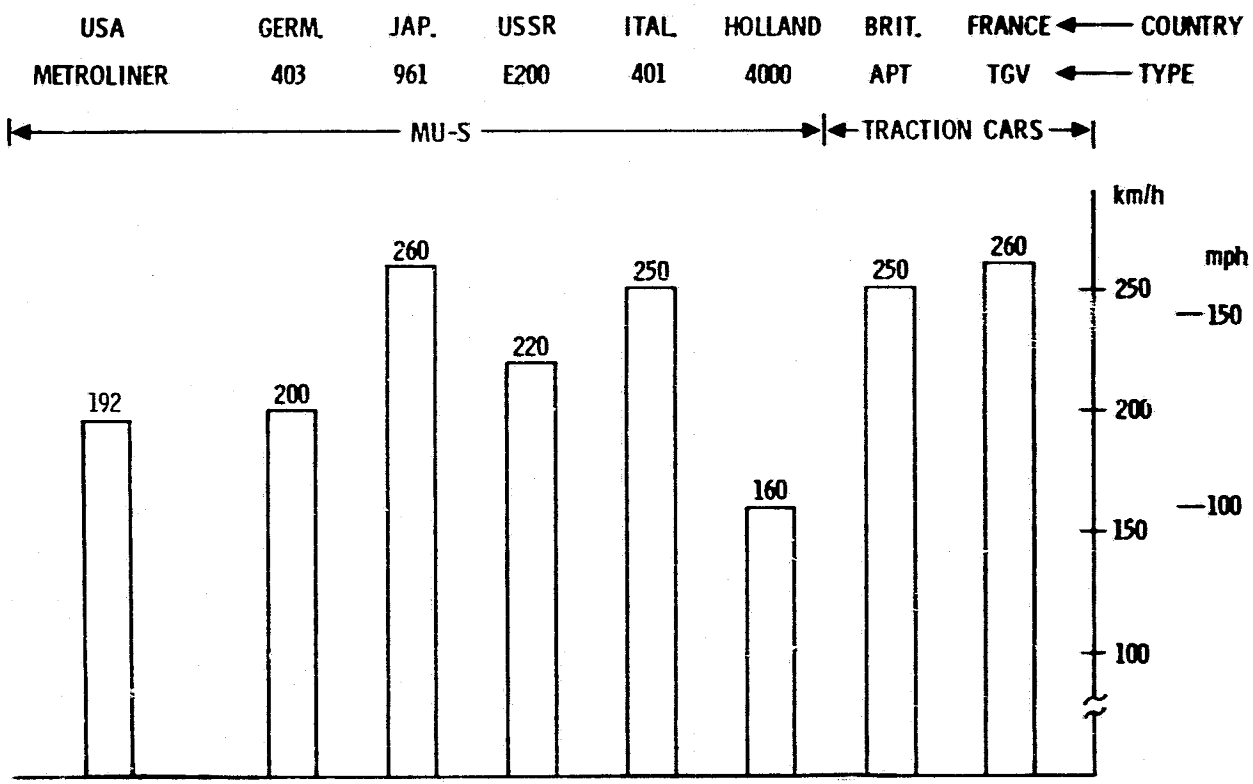


Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



MAXIMUM SPEEDS



HIGH SPEED TRAINS, OVERSEAS AND NEC

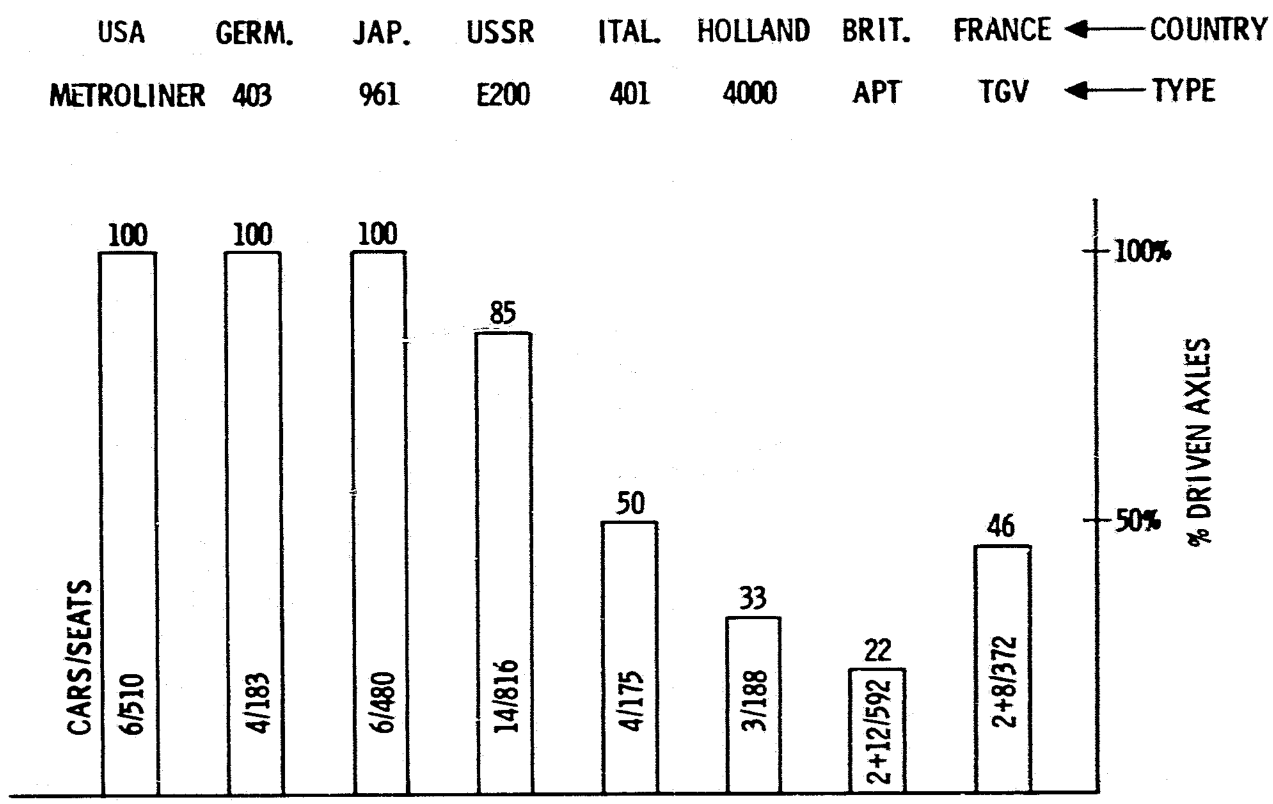
PERCENT DRIVEN AXLES, TYPICAL SIZE AND NUMBER OF SEATS

Multiple unit traction does not necessarily mean all-axle drive. Apart from the by-now obsolete German 403, Europeans seem to favor partial traction.

The British and French use two special traction cars per train for propulsion. These cars do not carry any passengers and essentially are extra lightweight locomotives.

The train size varies from 3 cars (Holland) to 14 cars (USSR); the number of passenger seats per train varies from 175 to 816.

% DRIVEN AXLES, TYPICAL SIZE AND NUMBER OF SEATS



HIGH SPEED TRAINS, OVERSEAS AND NEC

TARE WEIGHT

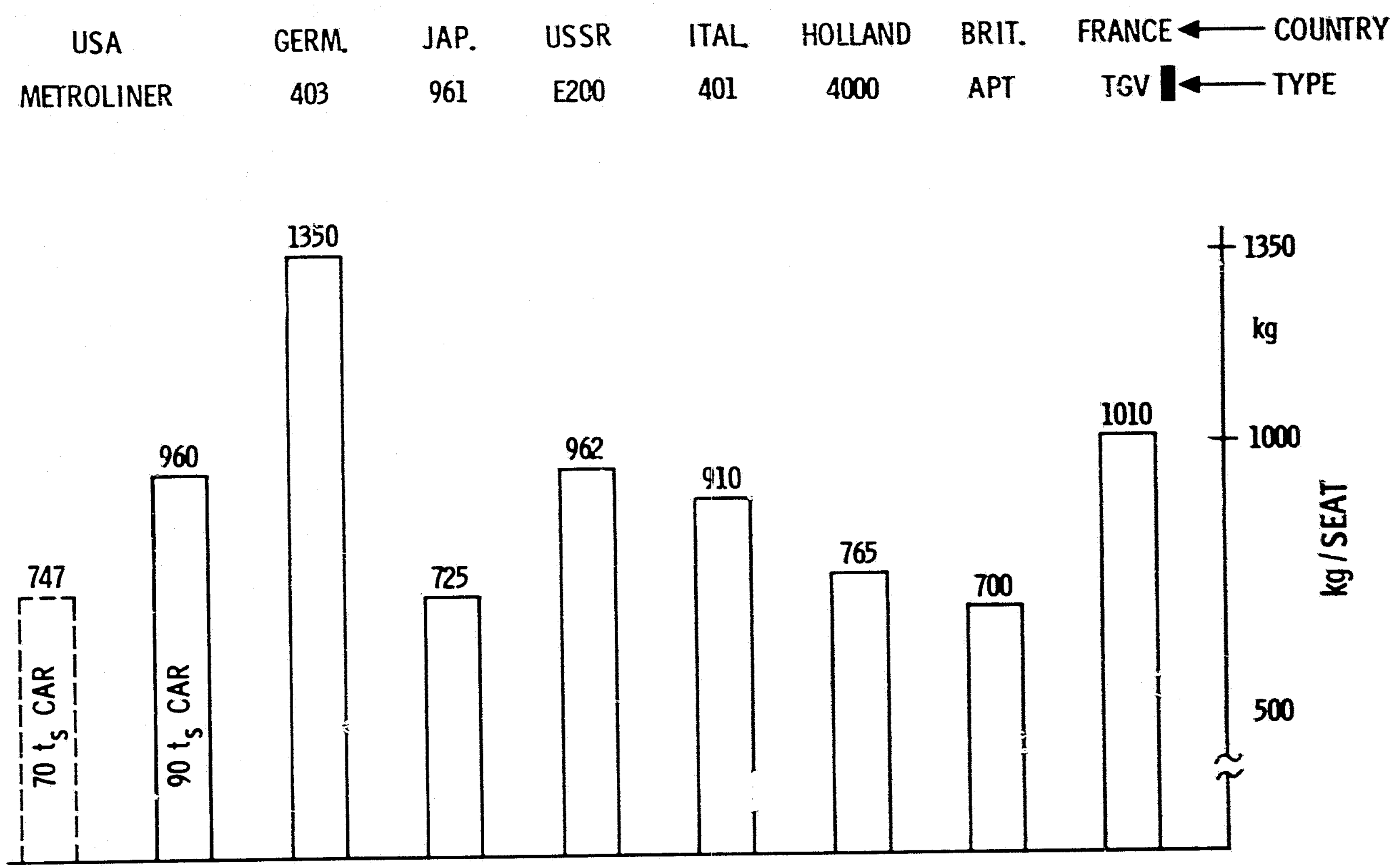
Tare weight per seat varies greatly in different countries. The more luxury provided, the higher the expected weight of the car. The luxury of the German 403 was partially responsible for its failure to enter revenue service. The French "Pride of the Century", the TGV, now entering the revenue service, can be considered the most luxurious train in Europe.

The U. S. Metroliner is a heavy car. Its weight would have to be reduced to 70 short tons to make it similar to Japanese, Dutch and British cars.

The lighter the car weight the less the energy consumption. Consequently the British APT is probably the most energy efficient European high speed train.

The term tonne (t) is being here used in order to designate the metric value (1000 kg = 2200 lbs). Term ton (t_s), if used, designates a short ton (909 kg = 2000 lbs).

TARE WEIGHT PER SEAT



HIGH SPEED TRAINS, OVERSEAS AND NEC

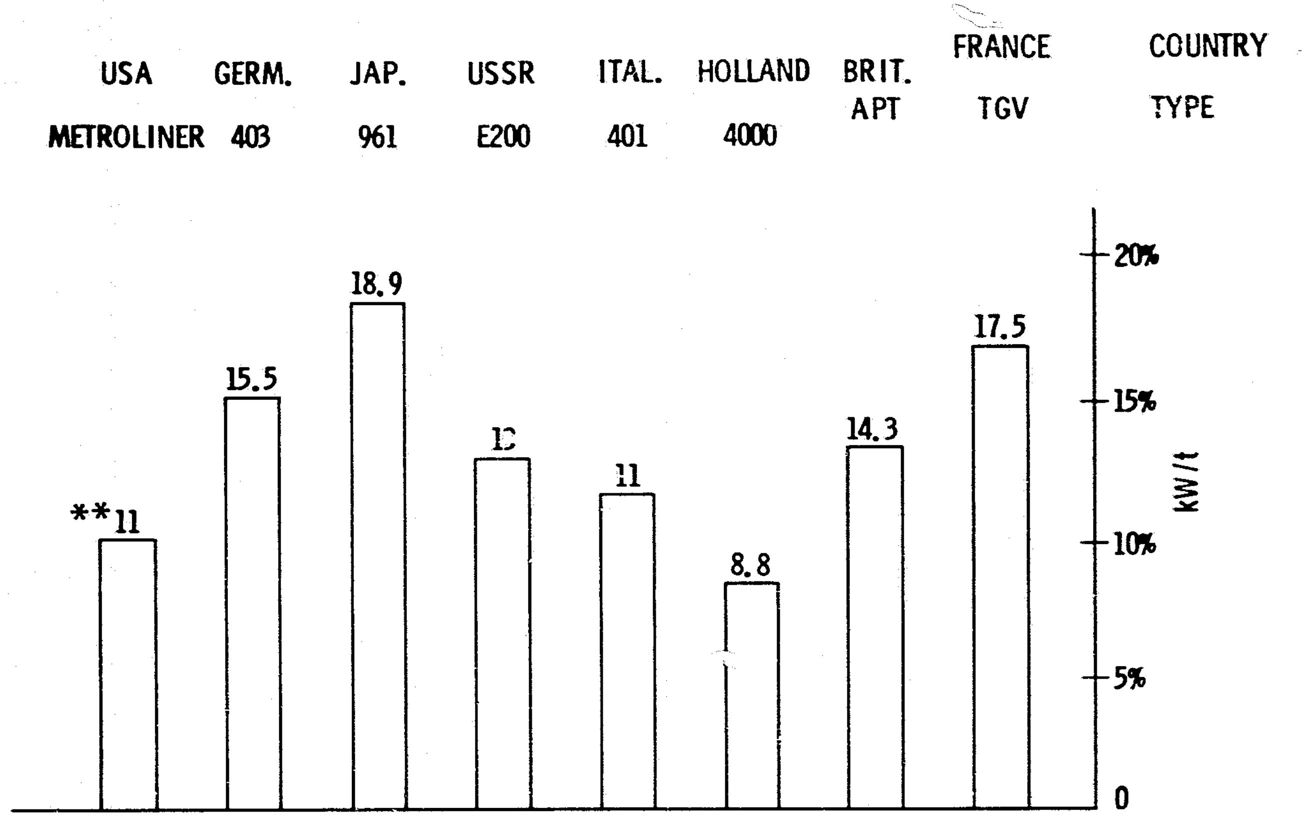
WHEEL POWER

The faster the train has to travel the more power it needs, especially if high acceleration capability is demanded.

Installation of very high wheel power is not always economically justified. Our studies indicate that further increase of tractive power of Metroliners on the existing roadbed would not greatly contribute to decrease of travel time.

The high ratings of Japanese and French trains may never be used. They may have been provided in order to extend the life, reduce the cost of maintenance, and increase the ability to meet schedules in case a portion of the equipment fails.

WHEEL POWER PER TONNE*



*TARE WEIGHT OF TRAIN IN METRIC TONNES.

**11 kW/t BECOMES 14.2 kW/t FOR 70 t (SHORT) METROLINER.

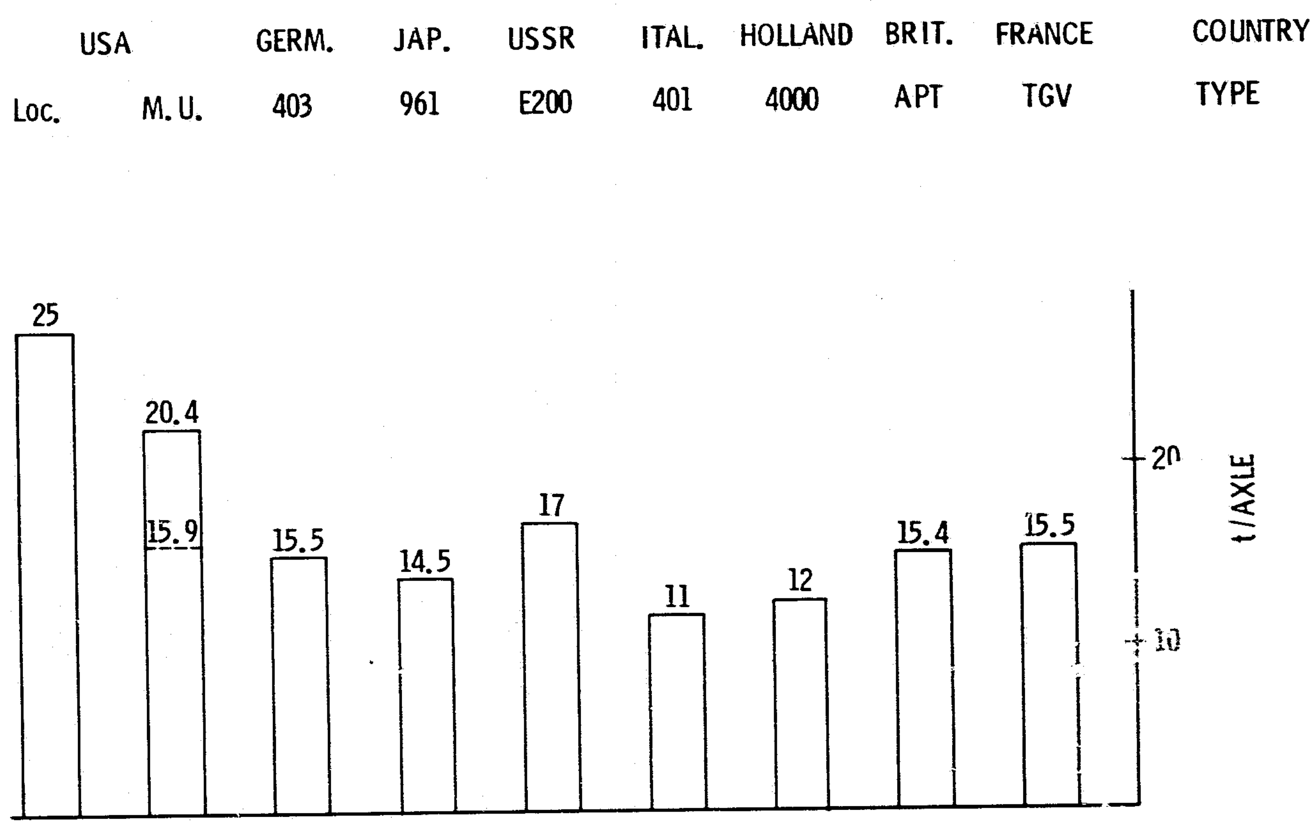
HIGH SPEED TRAINS OVERSEAS AND NEC

AXLE LOAD

Axle load of high speed trains should not be more than 16 tonnes, according to European standards. High axle load causes unwarranted deterioration of the track. Axle loads of the AEM7 locomotive as well as of the existing Metroliner are excessive in terms of European standards. There is no easy way to reduce axle load of a locomotive, so the British and French promote use of two traction cars in lieu of one locomotive.

Axle load of the Metroliner could be reduced to the European level by dropping the car weight from 90 short tons to 70.

AXLE LOAD*



*IN METRIC TONNES

**20.4 t/axle for 90 t_s (short) car and 15.9 t/axle for 70 t_s unit.

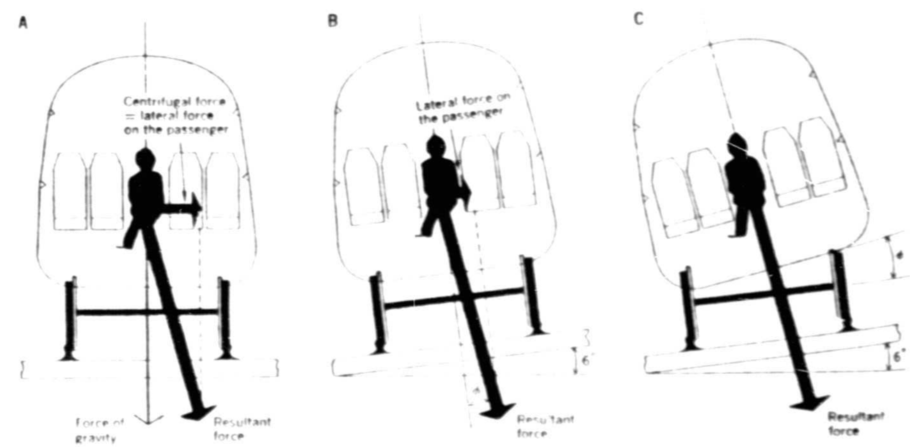
RAIL SUPERELEVATION AND BODY TILT

Tilted body cars are used by the British, Italians, Swedes and Japanese Their use permits negotiating curves faster without generat ng discomfort to passengers.

Body tilt is achieved by means of a hydraulically or a pneumatically operated mechanism.

Use on NEC would permit negotiating curves faster and thus contribute to shorter trip time reducing cost of track improvements by eliminating need for major relocation of many curves. This would be particularly applicable to the NEC-N section. The cost of the cars would certainly be greater.

BODY TILT



A NO COMPENSATION OF CENTRIFUGAL FORCES

B PARTIAL COMPENSATION BY RAIL SUPERELEVATION

C FULL COMPENSATION BY RAIL SUPERELEVATION AND COACH TILTING

NEC ROUTE CHARACTERISTICS

The route characteristics and resulting admissible track speeds effectively determine both time and energy performance.

This study considered the NEC as two separate sections: the southern one (NEC-S) between Washington, D.C. and New York City and the northern one (NEC-N) between New York City and Boston.

The existing route is not fully dedicated, nor engineered for continuous very high speed operation. In many places near stations, speed restrictions are caused by tunnels, curves and competing traffic. Between the stations numerous curves, bridges, trestles and varying track quality impose local speed restrictions; consequently, frequent accelerations and brakings characterize the NEC operation. The route runs through relatively flat country; the few grades do not significantly influence performance.

Some amount of fundamental upgrading and track realignment, in contrast with pure rehabilitation and maintenance, was found necessary to attain time performance specified by legislation. Elimination of all associated speed restrictions or major re-routing was assumed to be too costly or detrimental to the character of the service.

ROUTE CHARACTERISTICS

<u>NEC-S</u> Washington, D.C. - New York City

Distance: 226 miles (362 km)

Stops (75 sec. ea.): Baltimore - Wilmington - Philadelphia - Trenton - Newark

<u>NEC-N</u> New York City - Boston

Distance: 232 miles (371 km)

Stops (75 sec. ea.): Bridgeport - New Haven - New London - Providence - Route 128

NEC SPEED PROFILES*

Site-specific conditions prevent operating trains at constant high speed between the individual stations. All proposed speed profiles include a great number of acceleration and braking operations usually with short segments of constant speed in between.

Various options of NEC-S operation were studied within the boundaries of Speed Profile A, which is very close to the profile in use in 1978, and the "ideal" Speed Profile G, as defined by Task 11S (Ref. 1). Detailed description of all the letter-indexed speed profiles can be found in the Ref. 2 document. The AMT5 Profile was used during simulation runs on NEC-S and is expected to satisfy the legislated time performance.

Operations on NEC-N were studied using two different speed profiles: BNY1, specified by Amtrak, and BNY2, generated by the NEC Project Office. Characteristics of the NB78 profile were also investigated.

*For tabulations of Speed Profiles see pages 52 - 55

NEC SPEED PROFILES

PROFILE	MAX SPEED MPH	NEC - SOUTH
A	105	Profile B limited in 1978 to 105 mph.
B	120	Best (fastest) profile on the 1970 track (Ref. 5).
C	120	Profile B with minor upgrade, superelevated curves, no realignment.
D	120	Profile C with major upgrades, Elizabeth curve realigned and superelevated; Susquehana bridge upgrade, for example.
AMT5	120	Profile proposed by Amtrak for implementation (Ref. 3).
E	135	Profile D with additional superelevation and realignment.
F	135	Profile G limited to 135 mph.
G	150	Task 11S profile (Ref. 1).
		NEC - NORTH
BNY1	120	Profile proposed by Amtrak in June 1977 (Ref. 3).
BNY2	120	Profile by NEC Project Office in August 1977 (Ref. 4).
NB78	120	Profile proposed by Bechtel Inc. in May 1978 (Ref. 6).

NEC TRACTION EQUIPMENT

The presently used heavyweight, 6-axle GG1 and E60CP locomotives will soon be replaced by a new lighter-weight 4-axle AEM7 locomotive.

The AEM7 locomotive can be considered to be the first generation of a modern all-electric passenger locomotive. Built under Swedish license by EMD (General Motors) it is intended to provide the service legislated by Congress. Performance of this locomotive is the subject of this study.

Locomotive-hauled trains use Amcoaches. Various lengths of trains were studied.

Presently a fleet of about 60 Metroliners provides a premium passenger service between New York City and Washington, D.C. A single train typically consists of 4, 6 or 8 cars. These cars are multiple unit (MU) type with all axles driven.

NEC ROLLING STOCK

EQUIPMENT IN USE

(Weight in Short Tons)

Multiple Unit Traction Cars:

- Metroliners - high powered, self contained, multiple unit cars: weighing 90 tons; 26 m (85 ft) long; with B-B trucks; Geared for DC motor drive rated at 900 kW (continuous) and 1720 kW (short-time duty). Max. speed of 240 km/h (150 mph).

Locomotives:

- GG1 locomotives serviced the corridor reliably and efficiently for a great number of years hauling trains at speeds up to 160 Km/h. They will no longer be usable after the conversion to 25 kV, 60 Hz power is accomplished.

- E60CP locomotives were built by the General Electric Co. to provide service on NEC during the transition period from 15 kV/25 Hz to 25 kV/60 Hz operation. Limited to a maximum speed of 150 km/h (93 mph), it failed to satisfy 200 km/h (125 mph) speed requirements. Its 30 tons/axle weight is considered excessive. Its 6 axle, Co-Co truck, configuration is not beneficial to wheel/rail interface on the curved track.

- AE7 Locomotive - Weight 100 tons, B-B trucks, 25 tons/axle, 4500 kW (continuous) and 6400 kW (short-time duty). Capable of supplying an adequate auxiliary power to Amcoaches, meets American structural requirements. Max. speed 192 km/h (120 mph).

Amfleet Coaches:

Used in all new Amtrak coach services in the USA. Lightweight (58 t_s), 26 m (85 ft) long, 4 axles. Has the same seating capacity as Metroliner cars. Requires auxiliary electrical power from locomotive for lighting, heating and air conditioning.

TRACTION EQUIPMENT

MULTIPLE UNIT TRAINS

NEC premium service utilizes Metroliner coaches. Each Metroliner has all four axles powered. Each of the DC, commutator-type motors has 4 poles weighing 985 kg and is rated at 225 kW continuous and 430 kW short time peak. Metroliner car weight of 90 short tons was used. These are acknowledged to be heavy cars; a next generation could probably be lightened 70 t_s, contributing to a more economical operation. One pantograph energizes two coaches. This study concentrated on a 6 car train.

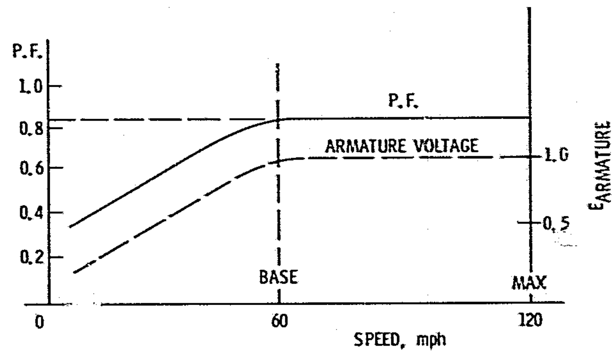
MULTIPLE UNIT TRACTION ADVANTAGES

(VS. LOCOMOTIVE HAULED TRAINS)

- Heavy axle load of a locomotive eliminated, so wear on roadbed smaller.
- Trip time is independent of train length.
- Better adhesion per train, so more reliability in maintaining schedules under all weather conditions.
- Train size easily adjustable to passenger density.
- No need to transfer locomotive to head of the train at terminal station. Saves time.
- Motive power proportional to size of train, so better on board power utilization.
- Better redundancy for propulsion.

EFFECT OF ELECTRICAL POWER FACTOR

Low Power Factor (P.F.) is associated with speeds below the base speed, where the armature voltage of the traction motors is controlled by varying the firing angle of the thyristors.



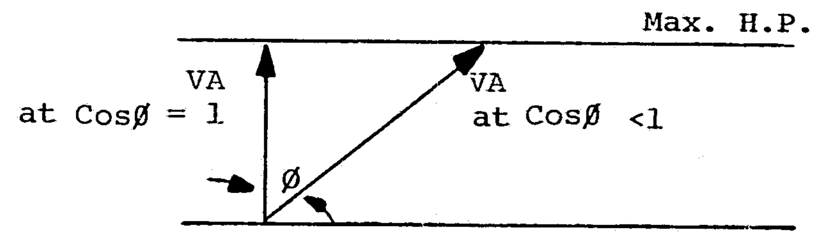
NEC passenger trains operate, for most of the time, above base speed, at reasonably good P.F.

The peak wheel power is rarely needed at high speeds, according to our simulation. Peak power is only used for acceleration.

At high speeds acceleration is accomplished very quickly. Non-availability of power to accelerate penalizes travel time very little.

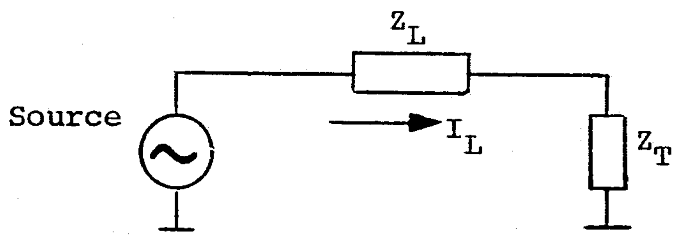
DELIVERY OF ELECTRIC POWER AT LOW POWER FACTOR

More of the apparent power (VA) must be delivered through the catenary, in case of a low power factor (Cos$\emptyset$), i.e. large $\emptyset$, for the equivalent max. horsepower at wheels.



Delivery of higher VA-s from the power substation to the train may be prevented by excessive line drop or because of the power limitations of the source.

Improving the power factor reduces the VA needed to generate the required wheel power.



Z_L - Line Impedance

Z_T - Train Impedance

I_L - Line Current, Proportional to VA demanded.

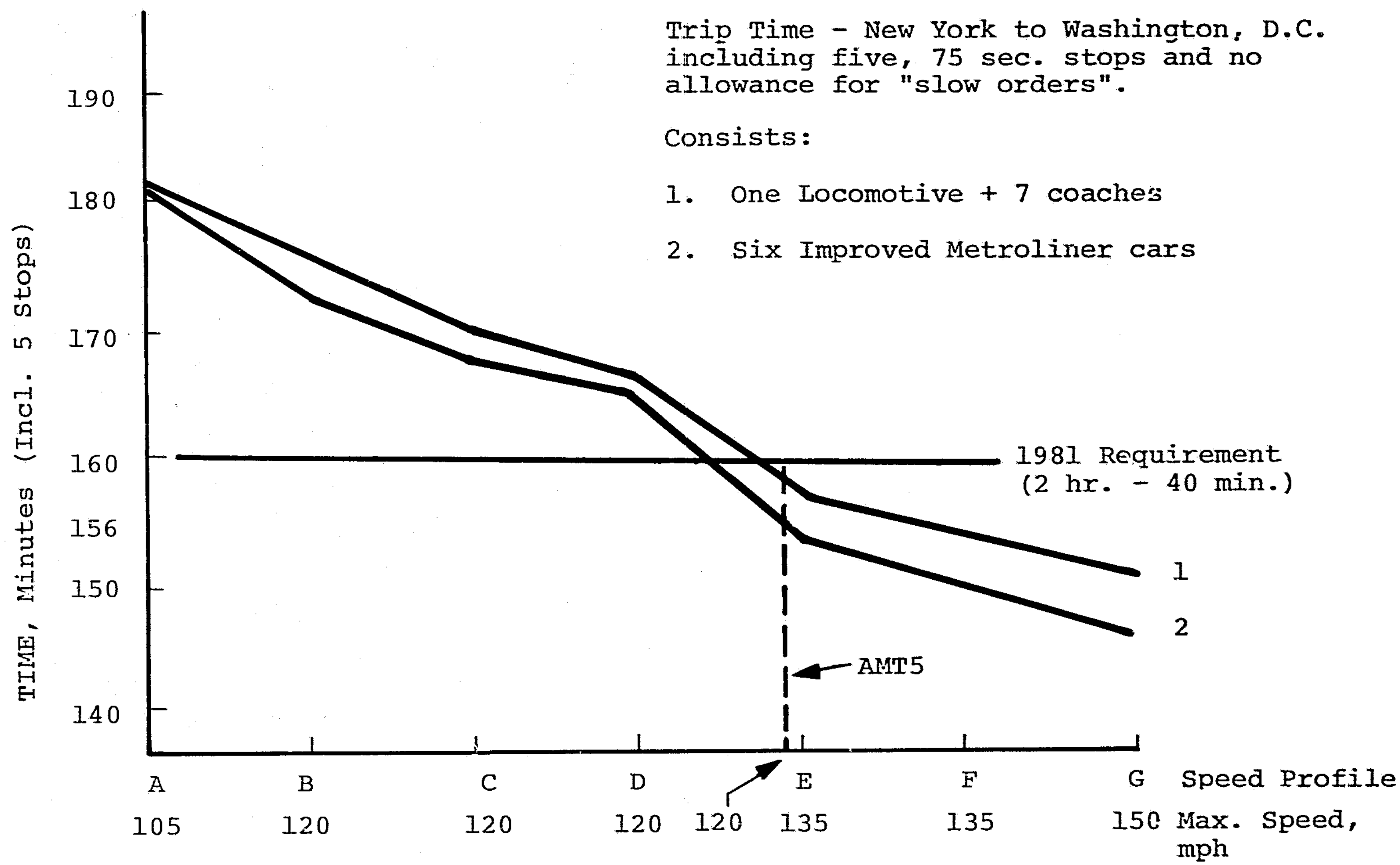
TRAIN PERFORMANCE ON NEC-SOUTH

TRIP TIME AT VARIOUS SPEED PROFILES

The facing graph gives the trip times for two trainsets that can be achieved depending on the track condition. The selected profiles with their maximum speeds, can be found on page 17. Total weights and aerodynamic constants are the same for the two trains. The train weight is 540 tons.

The MU train is the improved Metroliner. The locomotive hauled train is synthesized with 20% locomotive weight (108 tons), constant traction effort below 96 km/h and constant horsepower above 16 km/h. The locomotive is thus approximately equivalent to the AEM7 type.

It is to be noted that as the train conditions are improved, A to G, the time performance for both trainsets improves. 192 km/h top speed is common to the Speed Profiles B, C, D and AMT5; reduction of the trip time is achieved by a progressive elimination of the slowdowns. The short-time peak power ratings of the 6-car Metroliner is 10,600 kW and of the locomotive AEM7 5,250 kW. The failure of the locomotive-hauled train to perform as well as the Metroliner at speeds above 192 km/h (Profiles E, F and G) is due to lack of the available locomotive-peak power for acceleration and continuous locomotive power for overcoming of the aerodynamic drag.



*)For details see Ref. 7.

TRAIN PERFORMANCE ON NEC-SOUTH

SPECIFIC ENERGY AT VARIOUS SPEED PROFILES

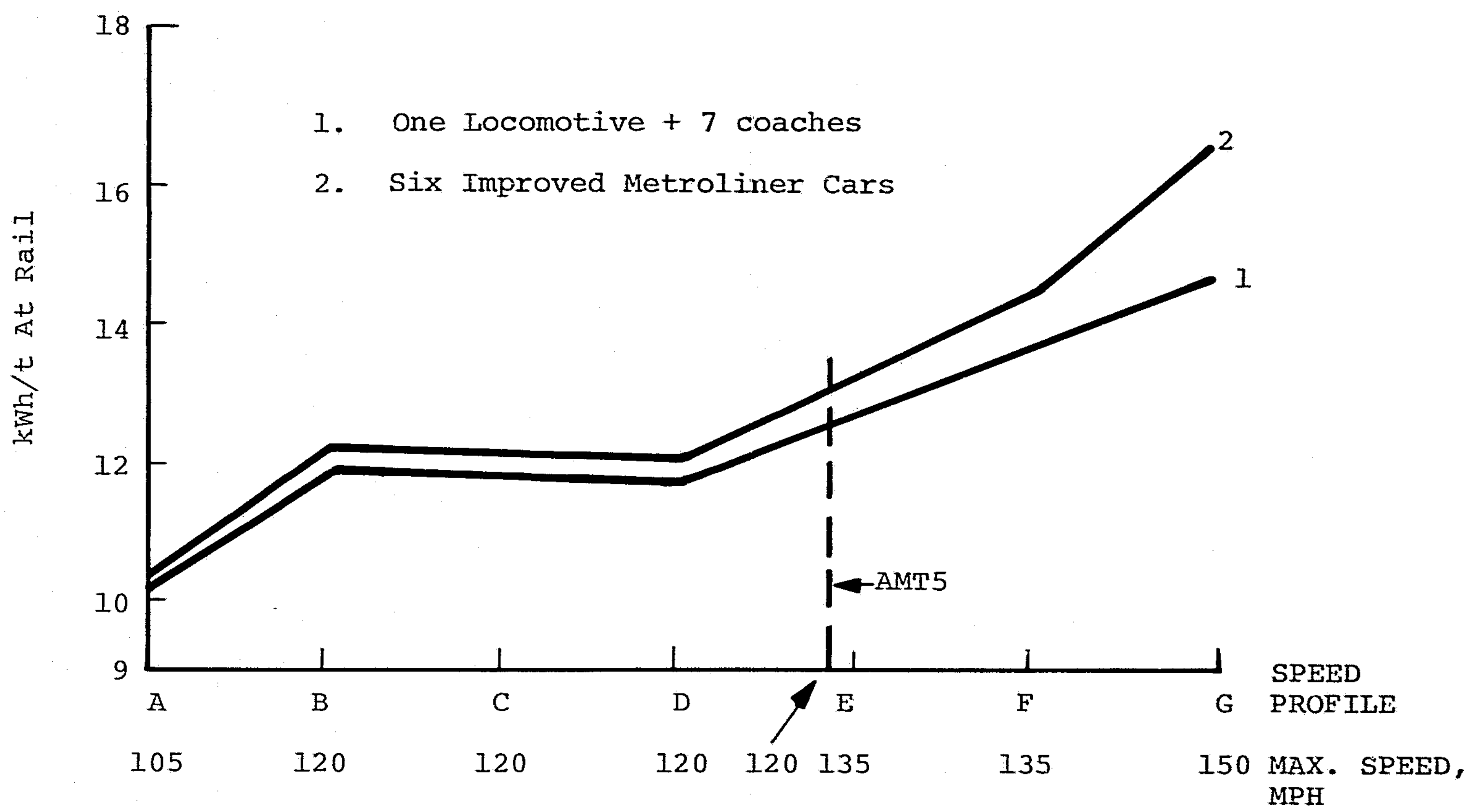
The facing graph gives the energy consumed for the trips of the preceeding trip time graph. This is energy transferred at the rail interface. It does not include any auxiliary energy such as traction motor blowers, energy losses associated with the power conditioning equipment, or motor efficiency.

The more powerful Metroliner runs faster but uses more energy to accomplish that.

The energy used actually decreases from profile B through D, thus the progressive elimination of slowdowns is definitely beneficial.

The widening gap in energy consumption between case 1 and 2, for 135 mph and 150 mph speed profiles E through G, reflects the penalty of shortening the trip time, as shown on the previous page.

SPECIFIC ENERGY - NEW YORK TO WASHINGTON



TRAIN PERFORMANCE ON NEC-SOUTH

TRIP TIME AS FUNCTION OF TRAIN SIZE

Simulation of operation of various sizes of train along the corridor between Washington, D.C. and New York according to the Amtrak's Speed Profile AMT5 is graphically presented on the facing page.

It can be seen that the one-locomotive-hauled 8-car trains will satisfy the trip time requirements, while the Metroliner gives a 4-minute shorter time irrespective of its length.

The larger energy consumption of the Metroliner is primarily due to its larger weight. The gap between the weight of the MU- and locomotive-hauled trains further widens with increase in the number of cars. The 4-car Metroliner weighs 360 tons, 4 coaches plus 1 locomotive about 330 tons; the 12-car Metroliner weighs 1080 tons, 12 coaches plus 2 locomotives about 900 tons. However it must be recognized that the Metroliner trip time is constant for all the train lengths whereas for locomotive-hauled trains the trip time increases with the addition of coaches as is shown.

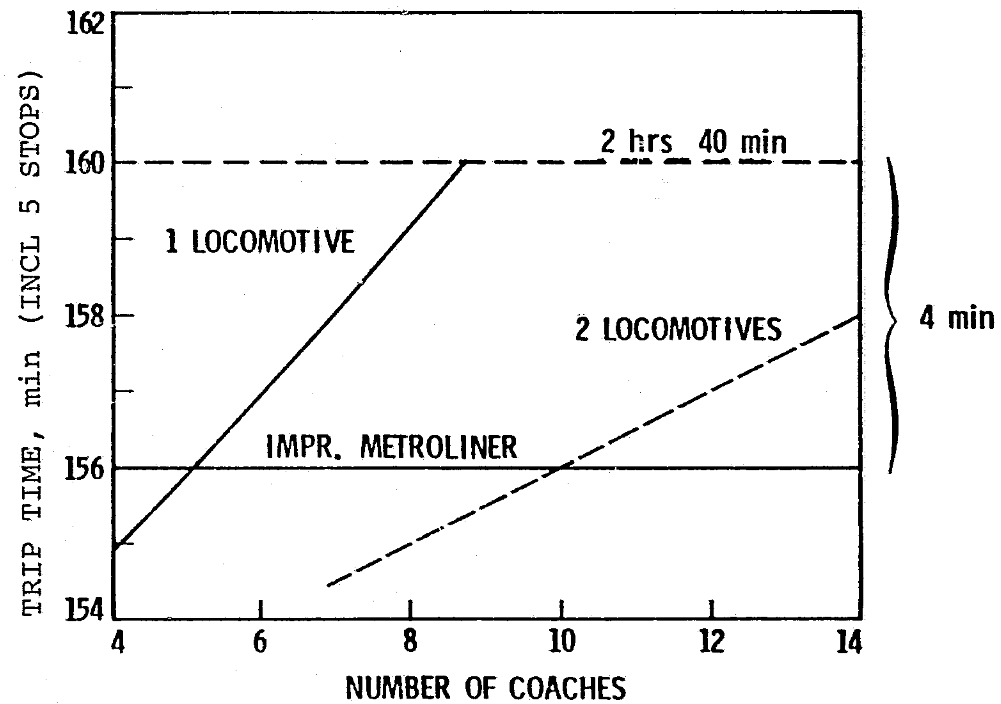
The Metroliner is acknowledged to be a very heavy car as compared with other MU-cars, shown on page 6. Reduction of the MU-car weight would help in saving energy.

NEC-SOUTH

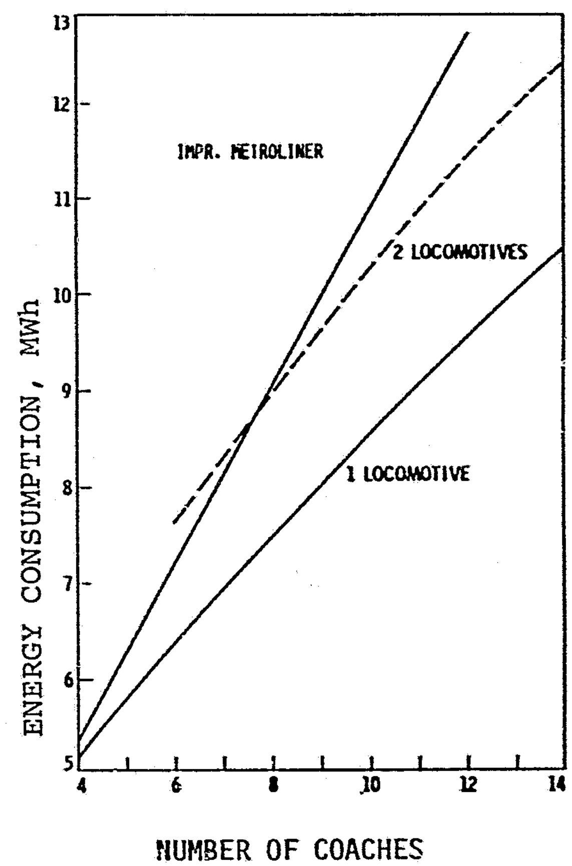
SIMULATION RESULTS

SPEED PROFILE AMT5, LOCOMOTIVE AEM7

TRIP TIME



ENERGY CONSUMPTION



TRAIN PERFORMANCE ON NEC-SOUTH

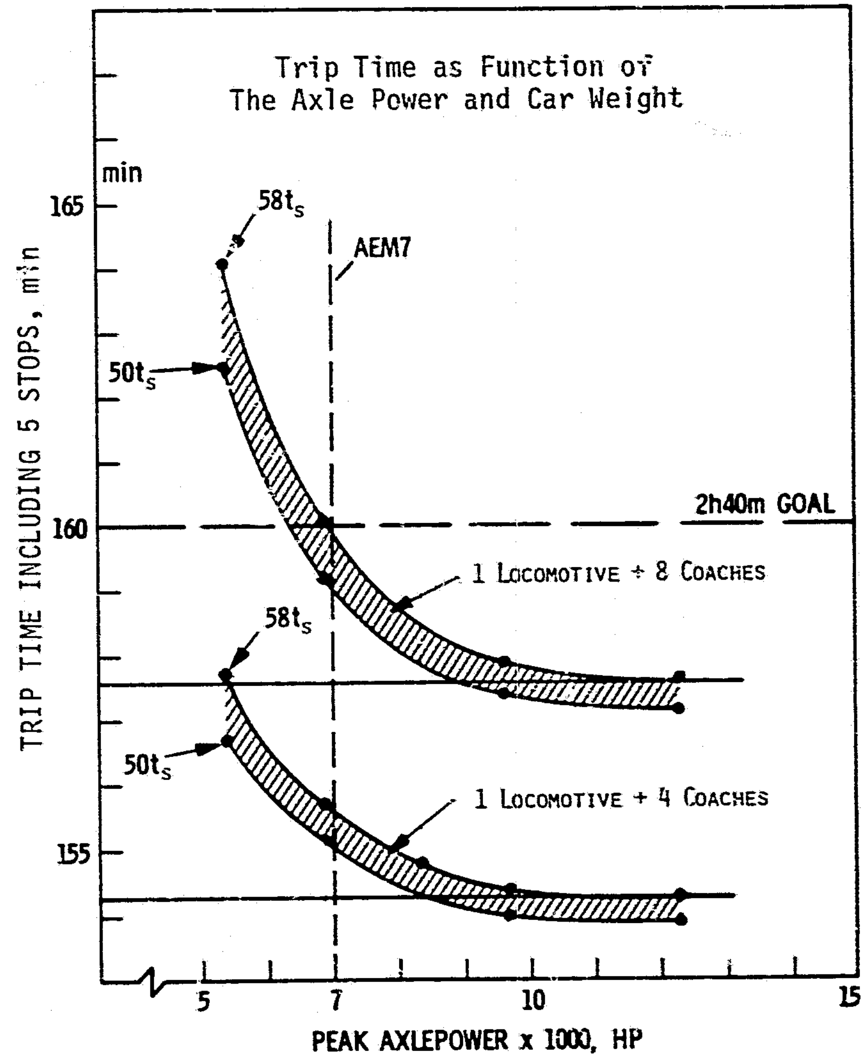
TRIP TIME AS FUNCTION OF AXLE POWER AND CAR WEIGHT

- Increase in train power results in an increased acceleration capability and leads to reduction of trip time. The amount of the decrease of the trip time becomes smaller as the axle power is increased. For the case investigated an increase of the locomotive power above some 9000 peak-HP does not significantly decrease trip time.

- Reduction of the weight of coaches from 58 t_s to 50 t_s could accomplish either of two things: (a) cut the travel time by 1/2 min. to 1 min. or (b) maintain the same schedule while reducing the peak load of the locomotive by 500 HP to 1000 HP.

- One Amtrak AEM7 locomotive hauling 8 coaches appears to satisfy the legislated trip time.

Locomotive Hauled Trains on NEC-S,
Operating According to AMT5 Speed Profile



TRAIN PERFORMANCE ON NEC-NORTH

TRIP TIME AS FUNCTION OF TRAIN SIZE AND SPEED PROFILE

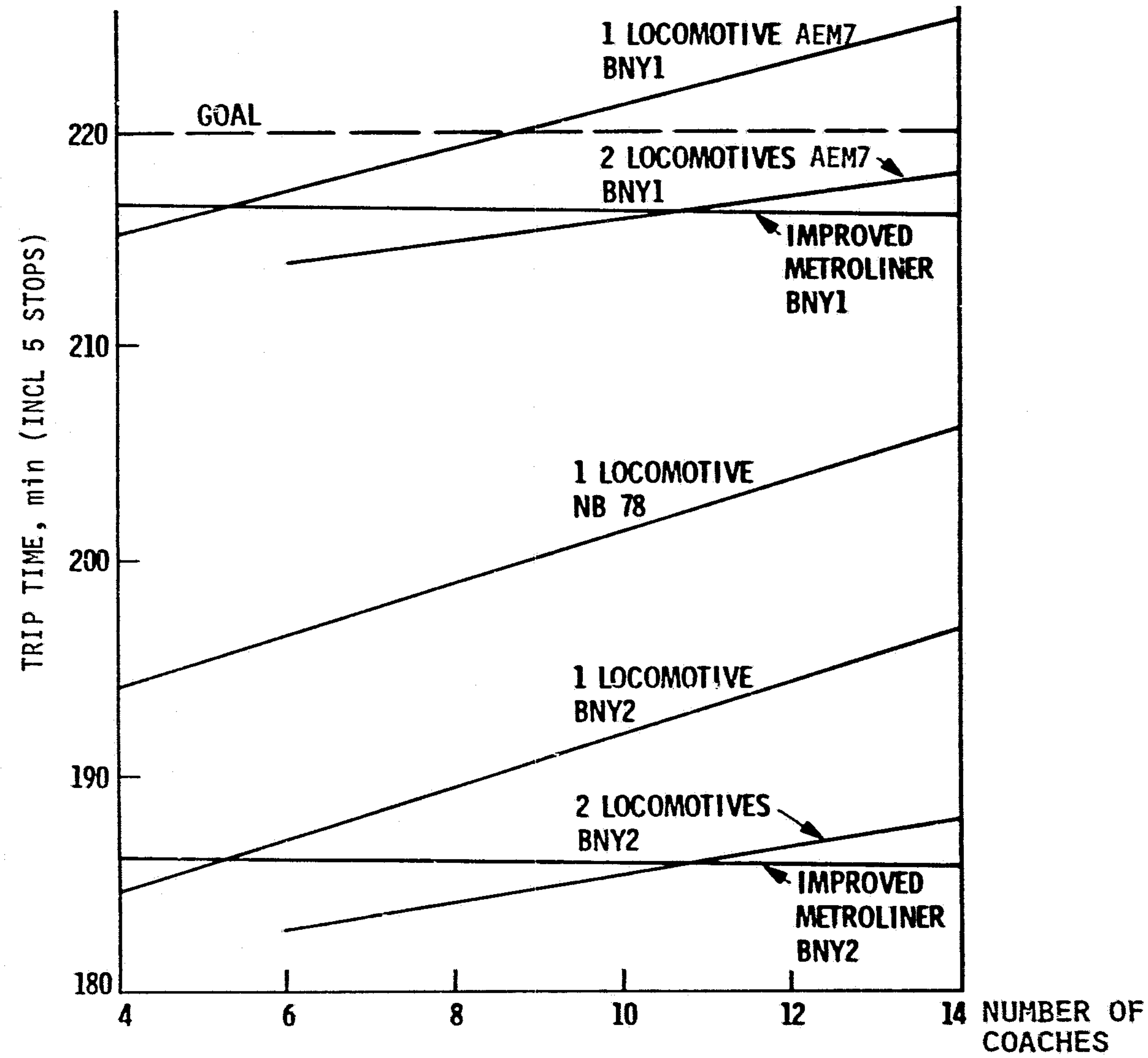
- The dependence of trip time on the severity of speed restrictions is dramatically shown on the NEC-North performance.

- The BNY1, BNY2 and NB78 profiles have the same maximum speeds of 120 mph. BNY1 has 26 segments of 120 mph and 4 other segments greater than 80 mph for a total of about 70 miles greater than 80 mph. BNY2 has 25 segments of 120 mph but 67 other segments greater than 80 mph for a total of about 150 miles greater than 80 mph.

- The goal of 220 minutes trip time between New York and Boston can be satisfied with the BNY1 profile by the Improved Metroliner or one AEM7 locomotive with 8 coaches.

- Energy considerations are similar to described for NEC-South. The faster the trip the greater the energy.

TRIP TIME USING BNY1, BNY2 AND NB78



TRAIN PERFORMANCE ON NEC-NORTH

ENERGY EFFICIENCY

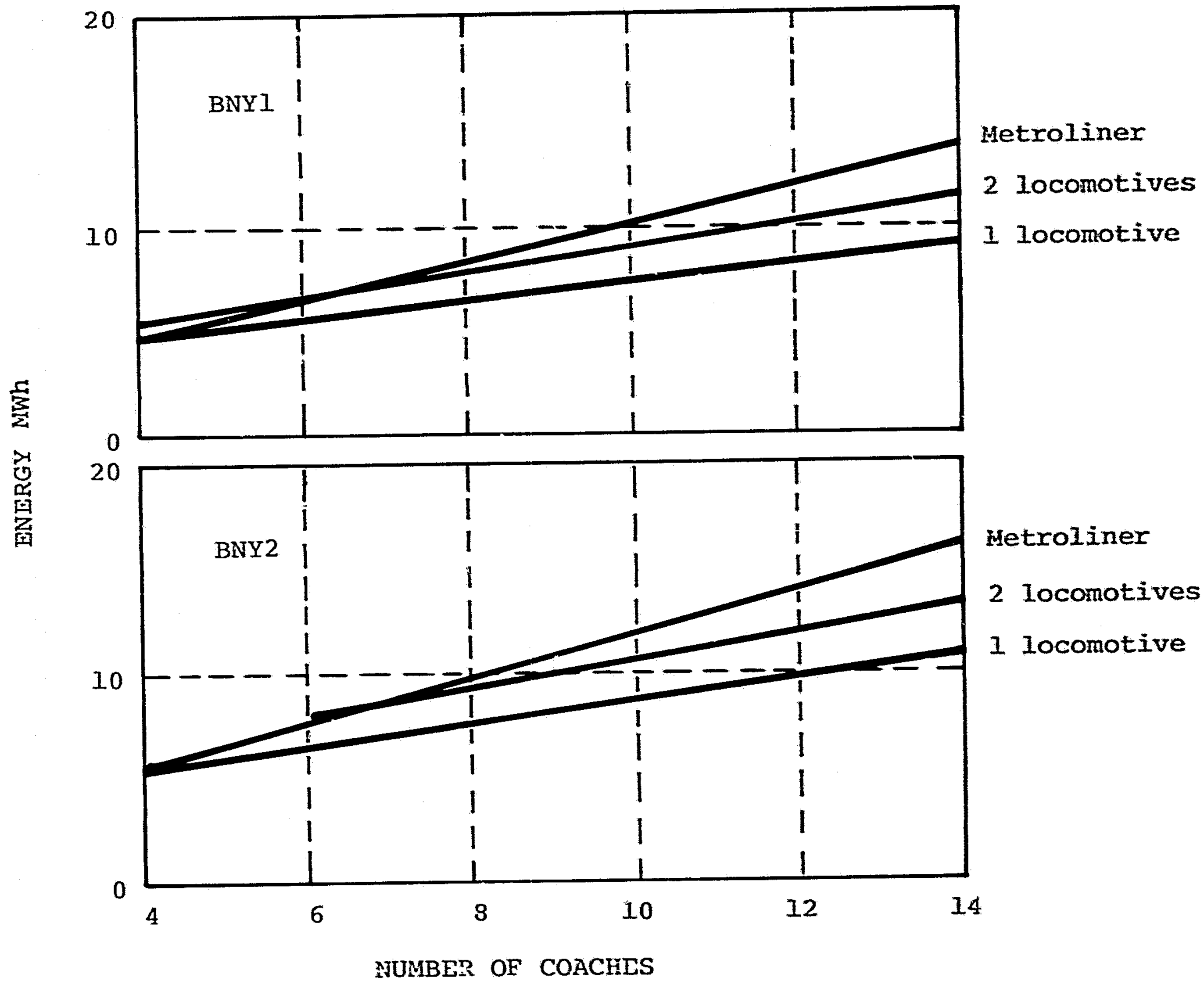
- The locomotive hauled trains are more energy efficient for the same trip times.

- The improved Metroliner is more energy-efficient than a two locomotive train with less than seven coaches.

- The energy consumption using BNY2 is 1 to 2 MWh greater than the energy consumption using BNY1.

- We have also established that the southbound trains required more energy than northbound trains, but the difference was of the order of 0.1 MWh.

NEC-N, ENERGY CONSUMPTION USING SPEED PROFILES BNY1 AND BNY2

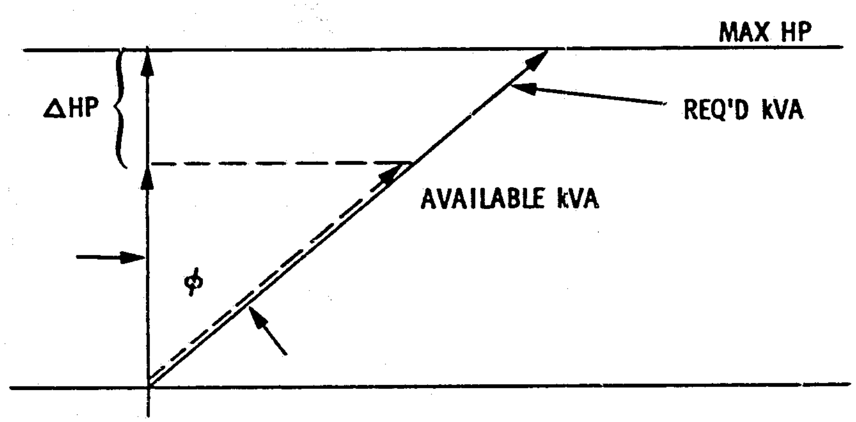


FACTORS AFFECTING OPERATION AND PERFORMANCE

LOW POWER FACTOR ON NEC

(See also page 22)

A low power factor condition was simulated by creating a 20% peak power deficiency and investigating the resulting penalty in trip time.



ASSUMED: ΔHP = 20% DEFFICIENCY

SIMULATION RESULTS

LOW POWER FACTOR IMPACT ON NEC

- Simulation of the trip on NEC-S, using AMT5 speed profile, has revealed that the peak power was demanded at 8 instances only, while accelerating to top speed. Non-availability of the peak power during these short intervals did not affect to any sizable degree the trip time.

- Similar conclusions were drawn from studies of NEC-N. The peak power at high speeds was needed so infrequently that reduction of peak power by 20% did not increase the trip times by more than a couple of minutes, at the most.

FACTORS AFFECTING OPERATION AND PERFORMANCE

BODY TILT

(See also page 12)

Without additional improvements of the track the body tilted train can decrease the trip times:

On NEC - South by 6 minutes

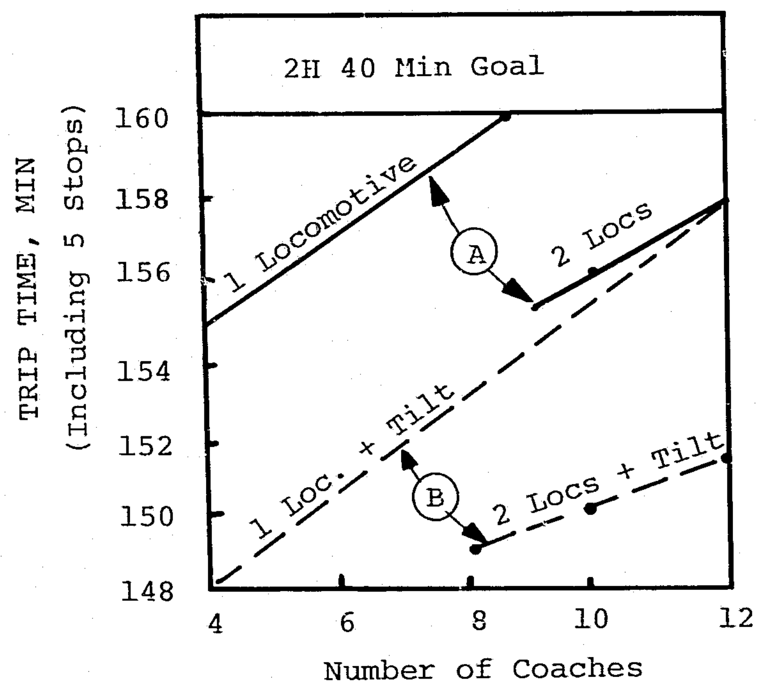
On NEC - North by 26 minutes

The faster travel always requires more energy. The simulation on NEC-N indicates a need for an additional 0.62 MWh (or 1.9 kWh/t_s) for a 4-car train and 0.93 MWh (or 1.2 kWh/t_s) for a 12-car train.

SIMULATION RESULTS

BODY TILT

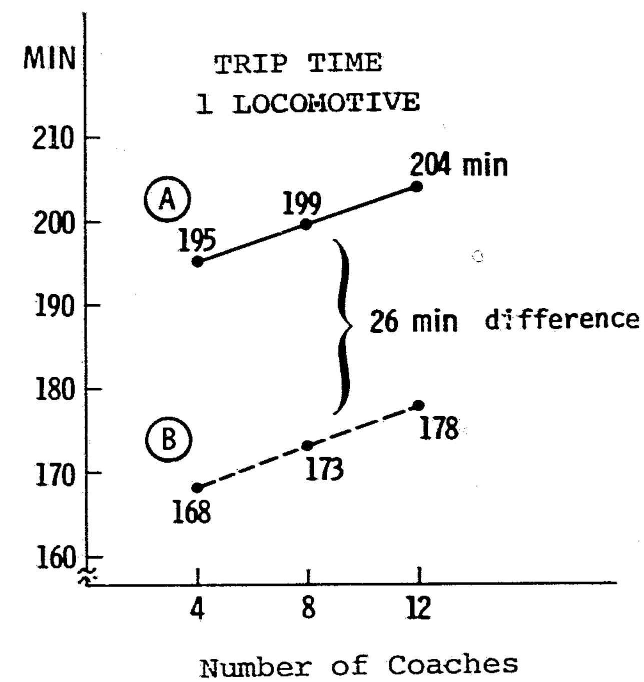
NEC-S



A = AMT5 Speed Profile

B = AMT5, With 30% Higher Speed on Curves

NEC-N



A = NB78 Speed Profile

B = NB78, With 30% Higher Speed on Curves

FACTORS AFFECTING OPERATION AND PERFORMANCE

MOTOR HEATING IN AEM7 LOCOMOTIVE

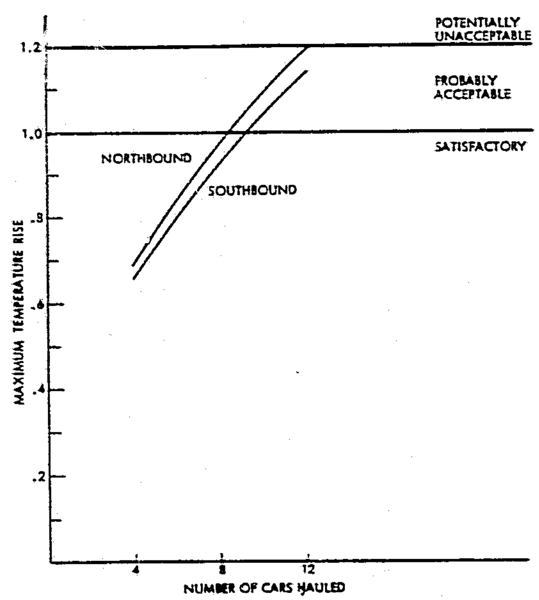
The objective of this study was to determine thermal behavior of the traction motors to be used by the AEM7 locomotive, hauling different size trains. The conclusions:

- Extensive operation at short-time ratings can cause motor overheating and damage.
- Peak ratings are required only for short periods for acceleration and dynamic braking.
- Number and duration of accelerations and brakings depends upon the speed profile used.
- Motor overheating was known to occur in operation of the Metroliner trains.

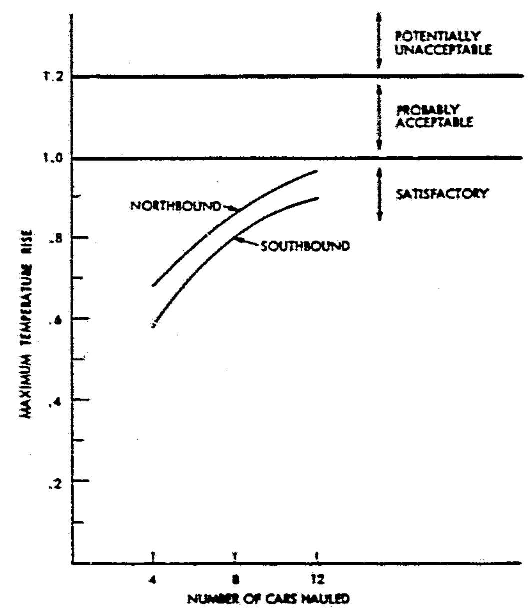
SIMULATION RESULTS

AEM7 LOCOMOTIVE

MAXIMUM MOTOR TEMPERATURE RISE



NEC-South
Speed Profile
AMT5



NEC-North
Speed Profile
BNY1

For details see JPL's Letter Report #13 (see page 57)

LOOK INTO THE FUTURE: AC-TRACTION

BACKGROUND

The possibility of employing an induction-type AC motor in lieu of the conventional DC machine has always been considered desirable. Speed control of such motors, however, necessitates use of a variable voltage and variable frequency source. Advancements in the solid state power conversion technologies made such a source available. First application of this technology dates back to the 1960's. Since that time power conversion equipment has been widely used by industry all over the world and has been progressively accepted by the railroad community.

AC TRACTION ASSESSMENT

Performance of the AC-driven Metroliners will not dramatically improve over that of the current Metroliners, because the travel time of a fixed body car is essentially governed by the roadbed condition and restrictions and not by the level of the applied power.

Utilized on the Northeast Corridor AC traction might reduce the cost of maintenance and improve the ride quality.

- Cost of maintenance should be lower because the solid state drive, when fully debugged, will operate care-free and the squirrel cage induction motors will require less maintenance and care.

- The ride quality will be improved because the generated tractive effort is less jerky, the very steep torque characteristic prevents any wheel slip, and a stepless speed control is available.

- The reduction of unsprung mass should diminish flange and rail wear - an important advantage that will help outweigh the cost of the more complex solid state equipment.

- The anticipated higher cost of procurement may very well be absorbed by the lower cost of maintenance of the rolling stock and infrastructure, so that the overall life-cycle cost may be lower.

LOOK INTO THE FUTURE: AC TRACTION

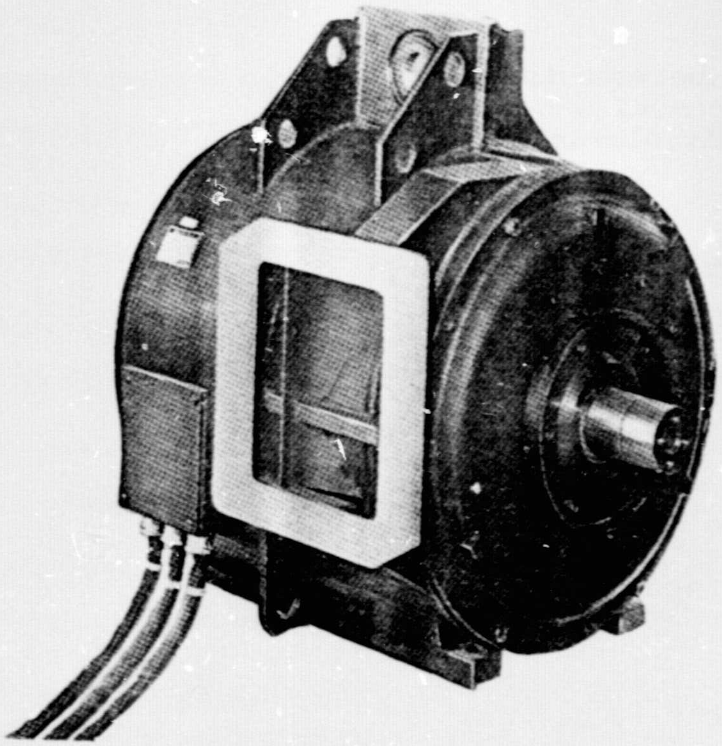
AC AND DC TRACTION MOTOR COMPARISON

The present Metroliners utilize commutator-type DC motors designated type W here. Two sizes of induction-type motors were used, to assess the performance of AC traction: The Brown Boveri (BBC) motor type QD335-S4 (for short, called S-motor) and a synthesized motor M, whose size is between the S-motor and the larger BBC QD335-N4 motor. The WE-1461 is a Westinghouse motor.

The induction-type S-motor is smaller than the commutator-type W-motor. It delivers 445 kW (continuous) as compared to 225 kW (continuous) or 430 kW (short-time) ratings of the W-motor.

The second induction-type motor, the M-type, is about 1/2-inch longer than the W-motor but it is capable of delivering 600 kW of power continuously.

AC AND DC TRACTION MOTOR COMPARISON



S-MOTOR TYPE QD 335-S4

MODEL	TYPE	DESIGNATION	DIA. mm	LENGTH mm	WT *) kg	RATINGS (kW) **)
QD335-S4	AC	S	660	857	1100	445
--	AC	M	660	990	1450	600
WE-1461	DC	W	660	975	985	225/ 430***

*) Questionable; gear and mounting weights were estimated.

**) Continuous

***) Short time

Specific power of the induction motors M and S varies between 2.42 and 2.47 kg/kW, whereas the presently-used commutator motor weighs 4.38 kg/kW.

LOOK INTO THE FUTURE: AC TRACTION

NEC PERFORMANCE

The facing graphs offer a comparison between the present day technologies, as represented by AEM7 locomotive-hauled and Metroliner trains using DC traction, and multiple-unit trains with AC traction.

DC traction Metroliners utilize W-Motors with all axles driven.

AC traction multiple-unit trains would not need all axles driven in order to match the performance of present-day technology.

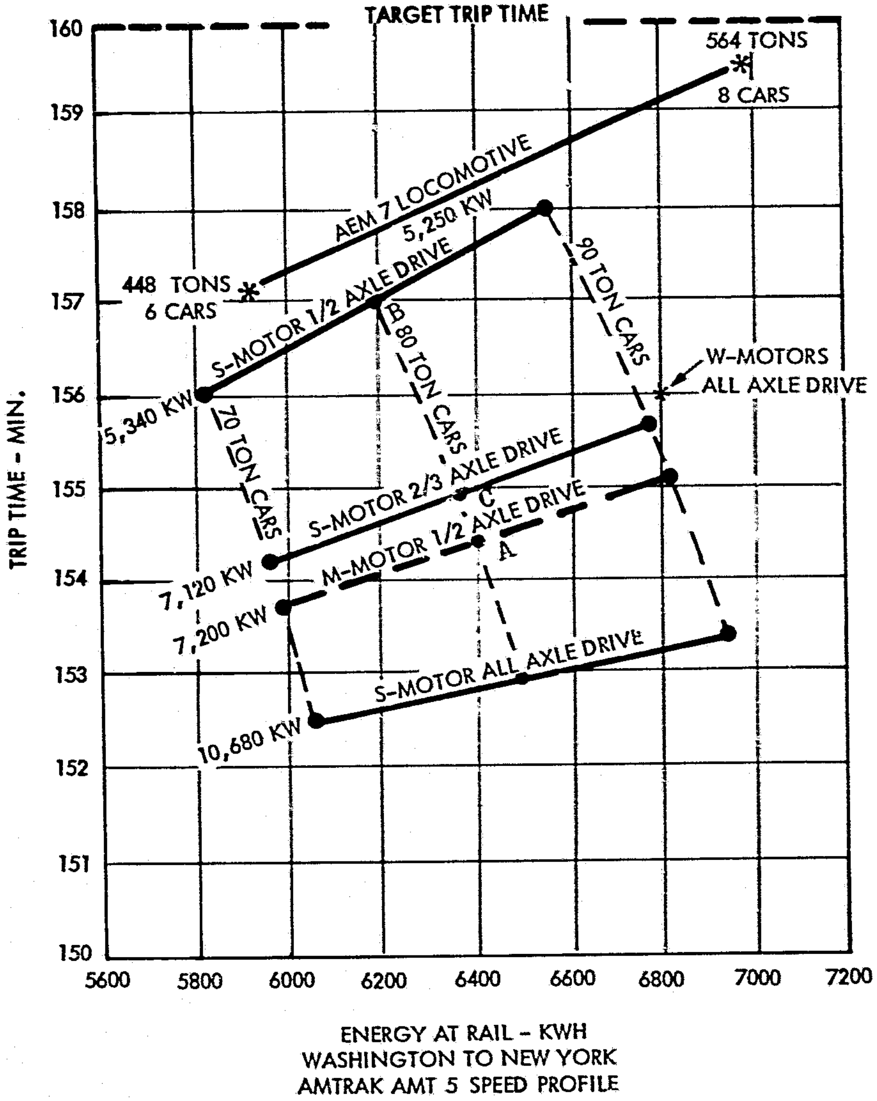
The DC-motor traction of today can be matched by using S-motors with only 1/2 or 2/3 of axles driven or M-motors with 1/2 axles driven. All-axle drive with S-motors is also shown.

Utilization of fewer motors should help reduce cost of procurement and maintenance.

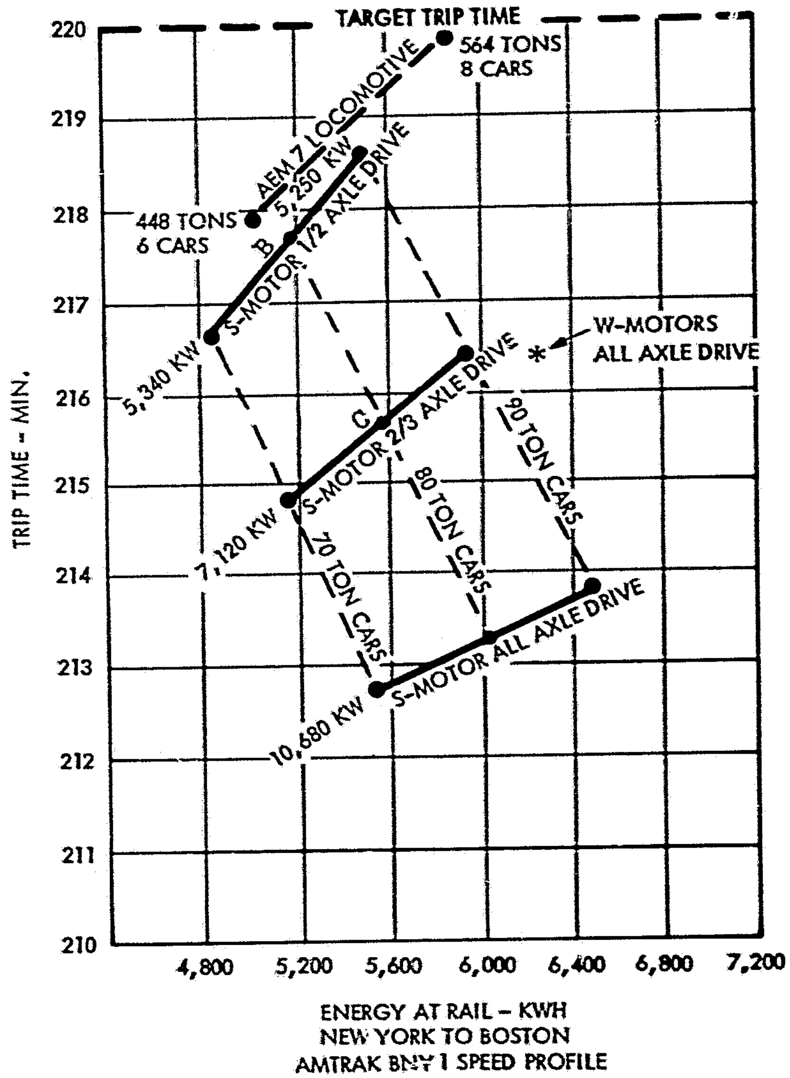
Reduction of the car weight from 90 tons (short) to 70 tons (short) would help conserve energy but would have little impact on travel time.

POWER-WEIGHT-TIME-ENERGY MAP (SIMULATION RESULTS)

NEC-S



NEC-N

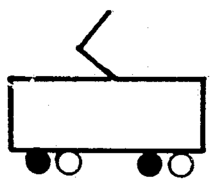


LOOK INTO THE FUTURE: AC TRACTION

AC TRACTION CONFIGURATION OPTIONS

6-CAR MULTIPLE UNIT TRAIN, BUILDING BLOCKS

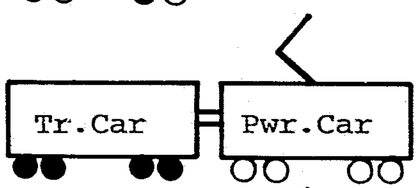
A



Single Car Set: A

1/2 Axle Drive, One M-Motor per Truck

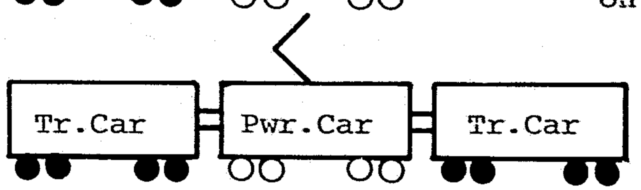
B



Two Car Set: B

1/2 Axle Drive, One S-Motor per Axle on Traction Car only.

C

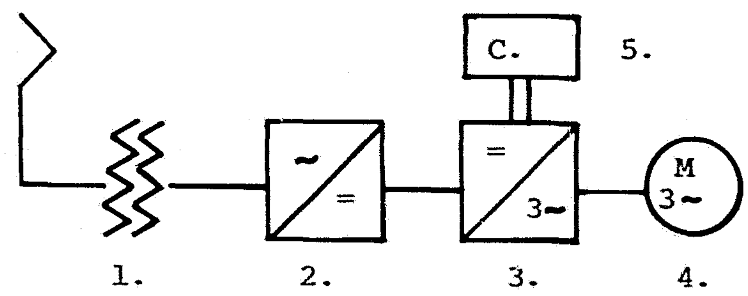


Three Car Set: C

2/3 Axle Drive, One S-Motor per Axle on Traction Cars only.

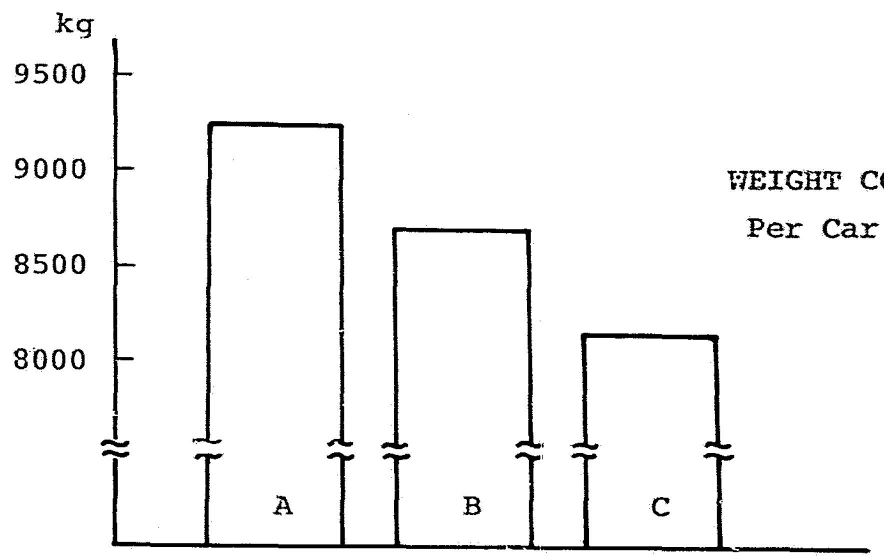
All the cars weigh 80 ts and are assumed to have the same seating capacity as the present-day Metroliners. Performance of the above options was presented on the previous page.

AC TRACTION ELEMENTS AND WEIGHTS



1. Transformer*)
2. Rectifier**)
3. Inverter
4. Motor (s)
5. Controller

*) Without Radiator & Blower
**) Without Forced Air Cooling
~: AC; = :DC.



WEIGHT COMPARISON

Per Car, Average

CONFIGURATION (see opposite page)

CONCLUSIONS

GENERAL

- TRACTION POWER

  No significant benefits are derived from using locomotives more powerful than the AEM7, or adding more power to Metroliner cars for speed profiles studied.

- TRIP TIME VS. MAXIMUM SPEED

  In the NEC an increase of the maximum allowable speed does not visibly decrease the trip time; it does however increase energy use significantly.

- TRACK IMPROVEMENT, MINIMUM SPEED

  The trip time is governed primarily by route configuration and roadbed conditions. Improving the track to raise the low speeds contributes most significantly to reducing the trip time, without affecting the energy consumption.

- BODY TILT

  Utilization of body tilt on curved track on NEC-North reduces the trip time by 26 min (13%).

- LOW POWER FACTOR

  A low power factor as encountered at below base speed, has a minimal effect on trip time.

- LOCOMOTIVE VERSUS METROLINER

  (a) The AEM7 locomotive is competitive with the Metroliner for legislated service on the NEC.
  (b) The Metroliners have the advantage of greater flexibility in service.

CONCLUSIONS

AC TRACTION VERSUS DC TRACTION

- EFFICIENCY:

  The overall efficiency for both systems is estimated to be about the same.

- LIFE:

  Life of the 3-phase AC motors is longer than that of the DC equivalents; the more complex solid state electronics of AC traction, once qualified, could last as long as the electronics of the presently used DC drives.

- MAINTENANCE:

  A considerably lower maintenance cost is predicted for AC traction. Operational experience from industry and European railroads is encouraging.

- WHEEL-TO-RAIL INTERFACE:

  Less wearout of wheels and rail is expected with AC traction, because:

  (a) The torque characteristic is smoother.
  (b) The unsprung mass of the truck can be made lower.
  (c) A much smoother dynamic braking down to zero speed reduces the wear of wheels.

- COST:

  The life cycle cost of AC traction may prove lower in spite of higher acquisition cost.

SPEED TABLE AMT5 -- NEW YORK-WASHINGTON

MP MILE POST AT NORTH END OF SPEED ZONE
MI LENGTH OF SPEED ZONE
MPH PERMITTED SPEED

MP	MI	MPH	MP	MI	MPH	MP	MI	MPH	MP	MI	MPH
0.00	.72	15	27.79	28.81	120*	11.72	6.15	120	92.12	.42	65
.72	.48	60	56.60	0.00	0	17.87	2.13	105	92.54	1.21	70
1.20	.20	50	56.60	17.95	120+	20.00	1.86	120	93.75	1.35	45
1.40	1.62	60	74.55	.64	90	21.86	1.04	100	95.10	.55	15
3.02	.67	70	75.19	5.62	120	22.90	1.00	90	95.65	0.00	0
3.69	1.74	120	80.81	.48	70	23.90	2.19	120	95.65	.35	15
5.43	.77	105	81.29	.57	50	26.09	.71	40	96.00	1.60	30
6.20	.20	100	81.86	2.76	120	26.80	0.00	0	97.60	.66	45
6.40	2.58	105	84.62	.12	50	26.80	.23	40	98.26	.45	50
7.68	.72	45	84.74	.50	40	27.03	.57	50	98.71	1.38	85
8.40	.50	35	85.24	.33	50	27.60	2.37	120	100.09	25.03	120
8.90	.47	60	85.57	1.63	75	29.97	.53	105	125.12	2.08	110
9.37	1.25	70	87.20	.30	70	30.50	28.90	120$	127.20	0.00	0
10.62	3.33	120	87.50	1.70	30	59.40	.96	100	127.20	1.20	110
13.95	.85	65	1.50	0.00	0	60.36	.64	85	128.40	.60	100
14.80	6.79	120*	1.50	.62	45	61.00	3.53	120	129.00	1.96	115
21.59	.51	105	2.12	.79	60	64.53	.99	105	130.96	2.04	30
22.10	1.47	120	2.91	.18	85	65.52	6.40	120*	133.00	1.70	95
23.57	.46	90	3.09	2.21	120	71.92	.58	100	134.70	.30	40
24.03	.65	95	5.30	.87	90	72.50	5.29	120*	135.00	.85	15
24.68	1.62	100	6.17	1.69	95	77.79	.70	100	135.85	0.00	0
26.30	.49	90	7.86	1.46	120	78.49	1.01	105			
26.79	.49	95	9.32	1.06	110	79.50	12.27	120*			
27.28	.51	100	10.38	1.34	105	91.77	.35	50			

SPEED MPH, *=135, +=130 C-282 TO -288, $=135 C-332 TO -340

SPEED TABLE BNY1 NORTHBOUND NEW YORK-BOSTON

MP MILE POST AT NORTH END OF SPEED ZONE
MI LENGTH OF SPEED ZONE
MPH PERMITTED SPEED

FROM MP	FOR MI	SPEED MPH	FROM MP	FOR MI	SPEED MPH	FROM MP	FOR MI	SPEED MPH	FROM MP	FOR MI	SPEED MPH
NEW YORK			72.00	.30	15.	123.80	.60	45.	185.30	.10	15.
0.00	.30	15.	72.30	0.00	0.	124.40	1.35	50.	185.40	1.00	25.
.30	4.10	50.	NEW HAVEN			125.75	.85	60.	186.40	.40	30.
4.40	.75	40.	72.30	.10	15.	126.60	2.20	70.	186.80	1.65	70.
5.15	.30	60.	72.40	.30	10.	128.80	3.20	60.	188.45	.40	30.
5.45	1.45	120.	72.70	.90	35.	132.00	.60	50.	188.85	.85	60.
6.90	1.40	65.	73.60	2.30	60.	132.60	3.30	60.	189.70	.40	30.
8.30	.35	30.	75.90	1.85	70.	135.90	.80	50.	190.10	.50	50.
8.65	1.15	105.	77.75	.50	60.	136.70	1.40	120.	190.60	3.00	120.
9.80	.20	40.	78.25	2.75	70.	138.10	.40	80.	193.60	.90	80.
10.00	.80	60.	81.00	.80	50.	138.50	2.35	75.	194.50	10.40	120.
10.80	.40	45.	81.80	.60	75.	140.85	.70	60.	204.90	2.10	80.
11.20	3.90	60.	82.40	3.10	80.	141.55	.65	65.	207.00	2.50	120.
15.10	.70	45.	85.50	.50	75.	142.20	.60	80.	209.50	4.30	80.
15.80	1.70	120.	86.00	1.00	80.	142.80	1.20	120.	213.80	1.70	120.
17.50	2.10	60.	87.00	.60	70.	144.00	1.00	75.	215.50	.70	80.
17.00	1.60	90.	87.60	4.00	80.	145.00	.45	70.	216.20	1.00	120.
18.60	2.70	120.	91.60	1.30	120.	145.45	1.75	120.	217.20	.20	50.
21.30	.90	70.	92.90	1.35	75.	147.20	1.00	75.	217.40	0.00	0.
22.20	.50	65.	94.25	.65	70.	148.20	1.30	80.	ROUTE 128		
22.70	1.00	120.	94.90	3.20	80.	149.50	1.15	120.	217.40	2.85	120.
23.70	1.90	65.	98.10	2.05	120.	150.65	1.10	80.	220.25	.45	80.
25.60	.50	40.	100.15	1.65	75.	151.75	.75	70.	220.70	1.30	120.
26.10	6.30	70.	101.80	.50	70.	152.50	1.30	80.	222.00	4.40	80.
32.40	2.10	60.	102.30	1.20	120.	153.80	.50	75.	226.40	.95	55.
34.50	6.60	70.	103.50	.50	80.	154.30	5.35	120.	227.35	1.15	35.
41.10	.40	45.	104.00	1.15	120.	159.65	.80	80.	228.50	.50	10.
41.50	5.00	70.	105.15	1.00	70.	160.45	7.30	120.	229.00	0.00	0.
46.50	1.10	120.	106.15	.45	60.	167.75	.45	90.	BOSTON		
47.60	7.00	70.	106.60	5.40	70.	168.20	2.25	120.			
54.60	.65	30.	112.00	.90	60.	170.45	1.00	80.			
55.25	.35	45.	112.90	1.80	70.	171.45	.85	75.			
55.60	0.00	0.	114.70	1.60	120.	172.30	2.10	80.			
BRIDGEPORT			116.30	.60	70.	174.40	5.60	120.			
55.60	1.00	45.	116.90	3.70	60.	180.00	1.20	80.			
56.60	10.30	70.	120.60	1.75	45.	181.20	1.80	45.			
66.90	1.85	120.	122.35	.65	25.	183.00	1.80	65.			
68.75	.75	70.	123.00	0.00	0.	184.80	.50	15.			
69.50	.50	60.	NEW LONDON			185.30	0.00	0.			
70.00	2.00	70.	123.00	.80	25.	PROVIDENCE					

SPEED TABLE BNY2 NORTHBOUND NEW YORK-BOSTON

MP MILE POST AT NORTH END OF SPEED ZONE
MI LENGTH OF SPEED ZONE
MPH PERMITTED SPEED

FROM MP	FOR MI	SPEED MPH
NEW YORK		
0.00	.30	15.
.30	4.10	50.
4.40	.75	40.
5.15	.30	60.
5.45	1.45	120.
6.90	1.40	65.
8.30	.35	30.
8.65	1.15	105.
9.80	.20	40.
10.00	.80	60.
10.80	.40	45.
11.20	3.90	70.
15.10	.70	45.
15.80	1.70	120.
17.50	1.20	90.
18.70	.90	60.
17.00	1.60	90.
18.60	2.70	120.
21.30	2.46	80.
23.76	.51	75.
24.27	1.32	80.
25.59	.58	55.
26.17	.24	70.
26.41	3.87	80.
30.28	1.34	100.
31.62	.73	95.
32.35	3.83	80.
36.18	.69	75.
36.87	.83	90.
37.70	1.67	100.
39.37	1.72	80.
41.09	.48	60.
41.57	.30	75.
41.87	3.65	100.
45.52	.76	95.
46.28	.78	90.
47.06	2.11	100.
49.17	.57	75.
49.74	2.77	100.

FROM MP	FOR MI	SPEED MPH
52.51	.50	75.
53.01	1.59	100.
54.60	1.00	60.
55.60	0.00	0.
BRIDGEPORT		
55.60	.33	60.
55.93	.62	70.
56.55	1.11	100.
57.66	.73	85.
58.39	1.29	95.
59.68	.88	80.
60.56	.24	70.
60.80	1.23	90.
62.03	.48	75.
62.51	.55	90.
63.06	.69	95.
63.75	5.77	100.
69.52	.49	80.
70.01	1.05	160.
71.06	.97	45.
72.03	.27	35.
72.30	0.00	0.
NEW HAVEN		
72.30	.10	15.
72.40	.30	10.
72.70	1.87	45.
74.57	1.40	70.
75.97	1.80	105.
77.77	.49	65.
78.26	.40	70.
78.66	1.19	80.
79.85	1.49	65.
81.34	.49	55.
81.83	.40	100.
82.23	1.57	115.
83.80	4.06	120.
87.86	.58	110.
88.44	2.25	120.
90.69	.09	100.
90.78	.25	80.

FROM MP	FOR MI	SPEED MPH
91.03	1.85	120.
92.88	1.40	95.
94.28	.62	75.
94.90	1.20	120.
96.10	.52	95.
96.62	1.33	120.
97.95	1.65	115.
99.60	.55	95.
100.15	1.77	90.
101.92	4.21	120.
106.13	.51	60.
106.64	.83	80.
107.47	2.05	120.
109.52	2.50	80.
112.02	.88	65.
112.90	1.77	80.
114.67	1.00	120.
115.67	1.26	95.
116.93	1.61	65.
118.54	.35	55.
118.89	1.13	70.
120.02	2.00	85.
122.02	.23	80.
122.25	.33	40.
122.58	.42	30.
123.00	0.00	0.
NEW LONDON		
123.00	.11	30.
123.11	.82	50.
123.93	.43	45.
124.36	1.37	55.
125.73	.82	60.
126.55	1.14	115.
127.69	1.12	120.
128.81	.38	95.
129.19	.58	70.
129.77	.51	60.
130.28	1.65	90.
131.93	.68	55.
132.61	3.14	65.

FROM MP	FOR MI	SPEED MPH
135.75	.92	70.
136.67	1.48	120.
138.15	.24	85.
138.39	.70	80.
139.09	1.74	95.
140.83	.84	80.
141.67	.71	75.
142.38	.54	95.
142.72	.24	120.
142.96	2.04	85.
145.00	.40	75.
145.40	1.76	120.
147.16	1.32	105.
148.48	1.03	95.
149.51	1.11	120.
150.62	1.14	90.
151.75	.79	75.
152.55	1.09	95.
153.64	1.32	120.
154.96	.55	85.
155.51	15.93	120.
171.44	1.43	110.
172.87	.82	105.
173.69	.73	95.
174.42	5.58	120.
180.00	.17	85.
180.17	.33	80.
180.50	1.08	90.
181.58	.43	65.
182.01	.87	55.
182.88	1.95	65.
184.83	.07	40.
184.90	.40	15.
185.30	0.00	0.
PROVIDENCE		
185.30	.10	15.
185.40	.92	60.
186.32	.29	35.
186.61	.17	45.
186.78	1.64	70.

FROM MP	FOR MI	SPEED MPH
188.42	.18	55.
188.60	.30	30.
188.90	.90	60.
189.80	.30	30.
190.10	.45	45.
190.55	3.06	120.
193.61	.91	95.
194.52	10.41	120.
204.93	.37	110.
205.30	4.27	120.
209.57	.83	115.
210.40	.39	110.
210.79	3.07	115.
213.86	1.58	120.
215.44	.76	115.
216.20	1.00	120.
217.20	.20	50.
217.40	0.00	0.
ROUTE 128		
217.40	.10	50.
217.50	7.61	100.
225.11	2.13	95.
227.24	.15	55.
227.39	1.11	35.
228.50	.50	10.
229.00	0.00	0.
BOSTON		

SPEED TABLE NB78 NORTHBOUND NEW YORK-BOSTON

MP MILE POST AT NORTH END OF SPEED ZONE
MI LENGTH OF SPEED ZONE
MPH PERMITTED SPEED

FROM MP	FOR MI	SPEED MPH
NEW YORK		
0.00	.30	15.
.30	2.63	50.
2.93	1.05	85.
3.98	.63	30.
4.61	.36	55.
4.97	.51	65.
5.48	1.53	100.
7.01	1.46	55.
8.47	.31	50.
8.78	1.30	80.
10.08	.25	75.
10.33	.64	65.
10.97	.45	60.
11.42	2.14	70.
13.56	.35	60.
13.91	1.24	70.
15.15	.35	60.
15.50	.35	50.
15.85	1.61	120.
17.46	.36	115.
17.82	.80	80.
18.62	.38	40.
16.20	.24	20.
16.44	.23	55.
16.67	.92	75.
17.59	4.03	80.
21.62	1.08	75.
22.70	1.06	80.
23.76	.53	65.
24.29	1.31	75.
25.60	.57	60.
26.17	.26	70.
26.43	1.17	80.
27.60	2.68	75.
30.28	2.10	80.
32.38	.42	75.
32.80	.48	40.
33.28	1.40	80.
34.68	2.37	75.

FROM MP	FOR MI	SPEED MPH
37.05	3.50	80.
40.55	.49	75.
41.04	.45	45.
41.49	.31	75.
41.80	7.38	80.
49.18	.56	70.
49.74	2.79	80.
52.53	.49	70.
53.02	1.60	80.
54.62	.84	50.
55.46	.14	45.
55.60	.00	0.
BRIDGEPORT		
55.60	.95	45.
56.55	6.50	80.
63.05	.69	70.
63.74	5.77	80.
69.51	.48	75.
69.99	1.98	80.
71.97	.33	40.
72.30	.00	0.
NEW HAVEN		
72.30	1.41	50.
73.71	.25	45.
73.96	2.01	60.
75.97	1.80	85.
77.77	.49	65.
78.26	1.58	70.
79.84	1.13	65.
80.97	.37	60.
81.34	.49	55.
81.83	.37	85.
82.20	1.59	90.
83.79	1.73	120.
85.52	.51	75.
86.03	1.05	90.
87.08	.50	75.
87.58	.83	90.
88.41	2.78	120.
91.19	.47	90.

FROM MP	FOR MI	SPEED MPH
91.66	1.22	120.
92.88	1.39	80.
94.27	.65	75.
94.92	1.20	120.
96.12	.51	80.
96.63	1.04	90.
97.67	1.95	85.
99.62	.55	75.
100.17	.62	80.
100.79	1.14	90.
101.93	.38	70.
102.31	1.27	120.
103.58	.41	80.
103.99	1.20	120.
105.19	.97	95.
106.16	.48	55.
106.64	.84	75.
107.48	2.07	115.
109.55	.46	75.
110.01	.66	70.
110.67	1.39	75.
112.06	.40	65.
112.46	.47	70.
112.93	1.27	80.
114.20	2.79	75.
116.99	2.44	60.
119.43	.62	70.
120.05	1.06	105.
121.11	.48	50.
121.59	.75	80.
122.34	.26	45.
122.60	.40	40.
123.00	.00	0.
NEW LONDON		
123.00	.60	40.
123.60	1.15	50.
124.75	1.93	60.
126.68	1.00	100.
127.68	1.17	120.
128.85	.35	80.

FROM MP	FOR MI	SPEED MPH
129.21	.41	60.
129.61	.64	65.
130.25	1.16	85.
131.41	.58	70.
131.99	.67	55.
132.66	1.36	60.
134.02	1.85	70.
135.87	.58	60.
136.45	.25	95.
136.70	1.49	120.
138.19	.23	90.
138.42	2.43	80.
140.85	1.36	70.
142.21	.49	75.
142.70	1.27	120.
143.97	1.50	70.
145.47	1.75	120.
147.22	.32	110.
147.54	.38	85.
147.92	1.63	90.
149.55	1.12	120.
150.67	1.13	85.
151.80	.81	80.
152.61	1.18	90.
153.79	.57	75.
154.36	5.76	120.
159.62	.90	90.
160.52	9.91	120.
170.43	2.47	95.
172.90	.80	90.
173.70	.73	85.
174.43	5.58	120.
180.01	.15	105.
180.16	.79	95.
180.45	1.16	90.
181.61	.43	50.
182.04	1.01	60.
183.05	1.16	50.
184.21	.57	40.
184.78	.52	25.

FROM MP	FOR MI	SPEED MPH
185.30	.00	0.
PROVIDENCE		
185.30	.05	25.
185.35	.97	50.
186.32	.47	65.
186.79	1.86	70.
188.65	1.18	55.
189.83	.58	30.
190.41	.15	70.
190.56	3.07	120.
193.63	.90	85.
194.53	10.43	120.
204.96	.35	90.
205.31	1.20	120.
206.51	.56	95.
207.07	2.52	120.
209.59	1.20	100.
210.79	1.60	105.
212.39	.56	100.
212.95	.88	85.
213.83	1.66	120.
215.49	.68	100.
216.17	1.23	120.
217.40	.00	0.
ROUTE 128		
217.40	4.62	120.
222.02	.41	90.
222.43	1.04	95.
223.47	1.68	100.
225.15	2.06	85.
227.21	.10	80.
227.31	.31	25.
227.62	.88	35.
228.50	.50	10.
229.00	.00	0.
BOSTON		

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LETTER REPORTS

L.R. No.	Date	Title
4	11/77	Performance Comparison of Two Candidate Locomotives on the NEC.
5	11/77	Survey of European Electrified Railroads.
9	2/78	Performance Comparison of Locomotive-driven and Metroliner Trainsets on NEC.
10	2/78	Performance of Trains on NEC-South Using Speed Profile NL77-8.
11	3/78	Performance of Passenger Trains Using Two Different Speed Profiles.
12	3/78	Axlepower Requirements for Passenger Locomotives on the NEC.
13	5/78	Effect of Short-time Tractive Effort on Motor Temperature.
14	4/78	Soviet State Railroads, Equipment and Technology.
15	6/78	Chopper Technology Questions and Answers.
16	8/78	Trainset Running Resistance.
18	10/78	Three-phase AC Traction Study for MU-Trains on NEC.
19	1/79	Three-phase Traction for High Speed Passenger Service on NEC.